"Acoustic Emission Measurements on Real Reactor Components with Fracture Mechanical Interpretation" *

G. Deuster, Izfp, Saarbrücken, FRG.

(Presented by Dr. Sklarczyk)

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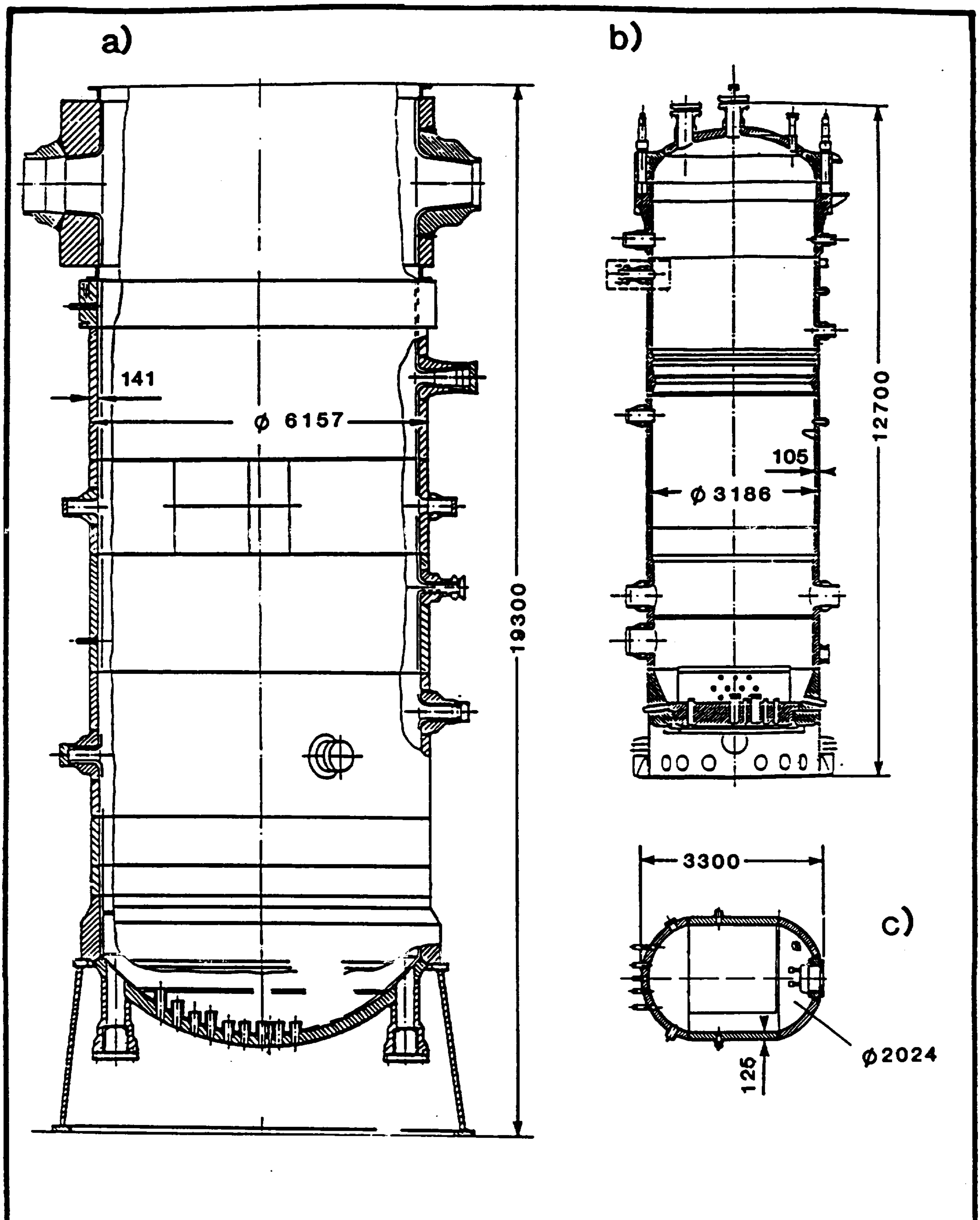
* In the handout a paper entitled "Results of Acoustic Emission during Mechanical and Thermal Loadings of Vessel Components and their Fracture Mechanical Interpretation" by H. Gries and E. Waschkies, Izfp, Saarbrücken, FRG; published in Nuclear Engineering and Design 106 (1988); was included.



a) large pressure vessel at the MPA

b) HDR pressure vessel

c) intermediate scale pressure vessel ZB2

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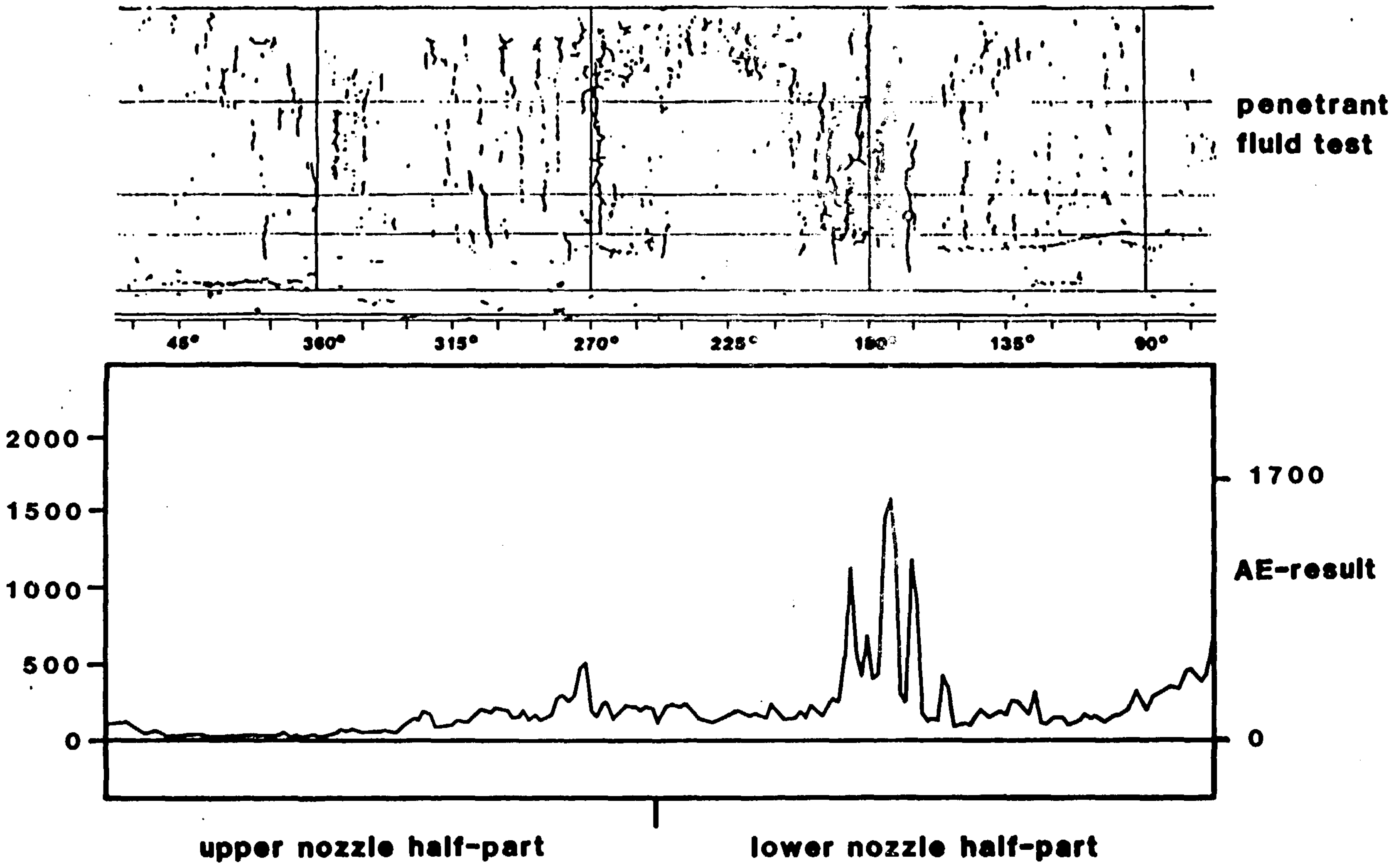
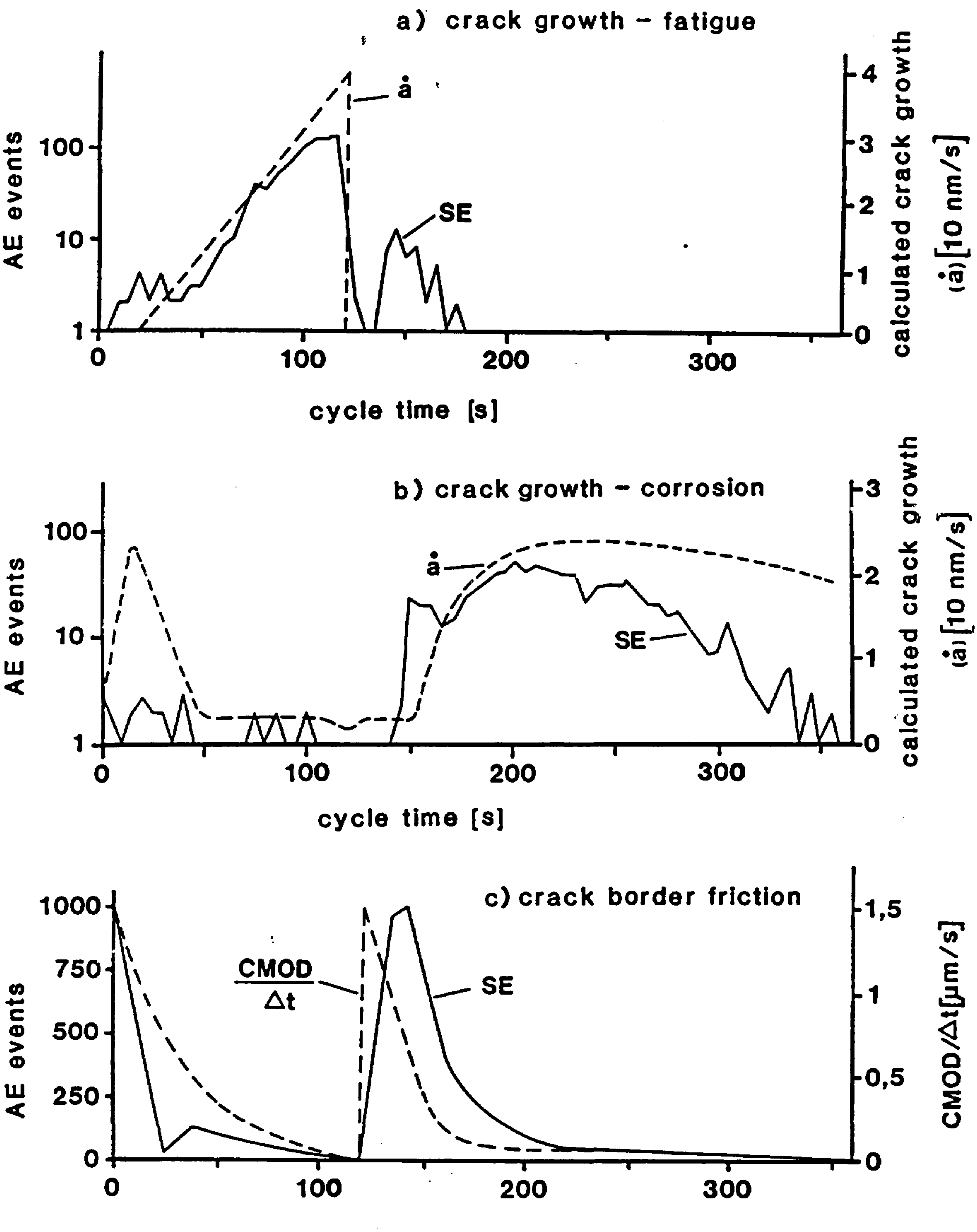


located signals (without filter) at the A2-nozzle
during the thermal shock test V6641 (4400-4800 load cycles)



classification and interpretation

of AE–signals

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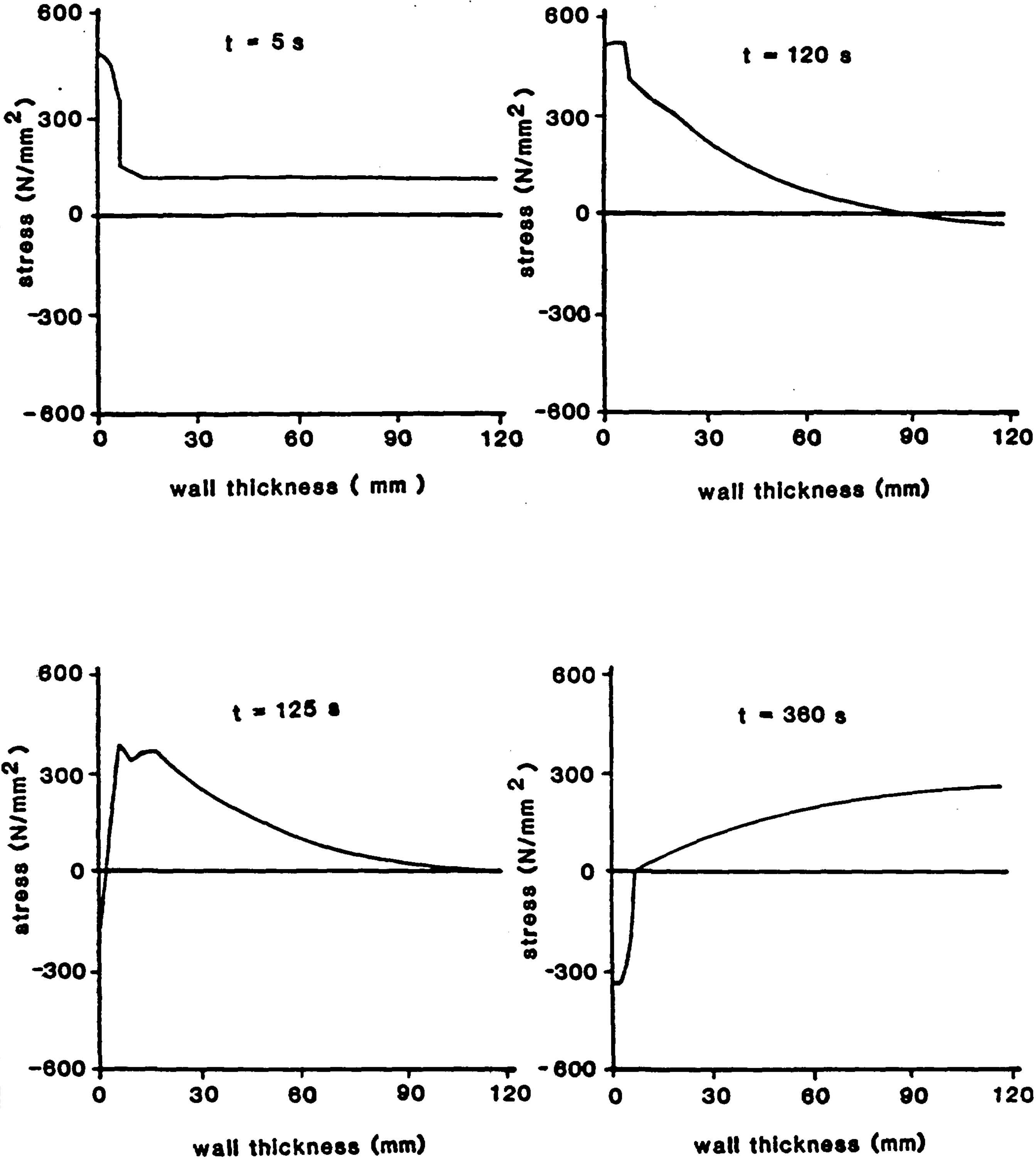
Figure 2



t: time after cooling

stress in the wall of a pressure vessel during the thermal shock (HDR)

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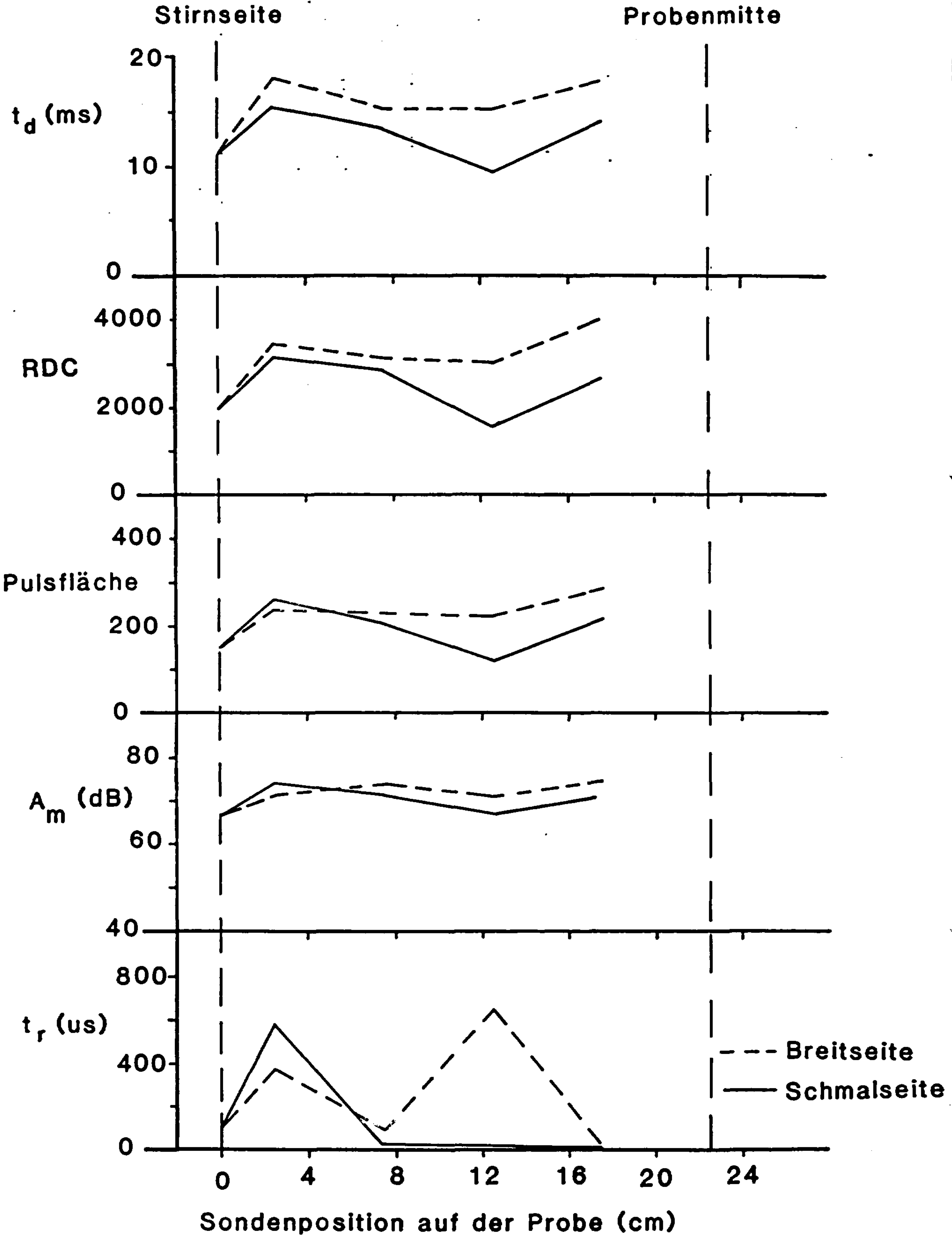
Figure 6



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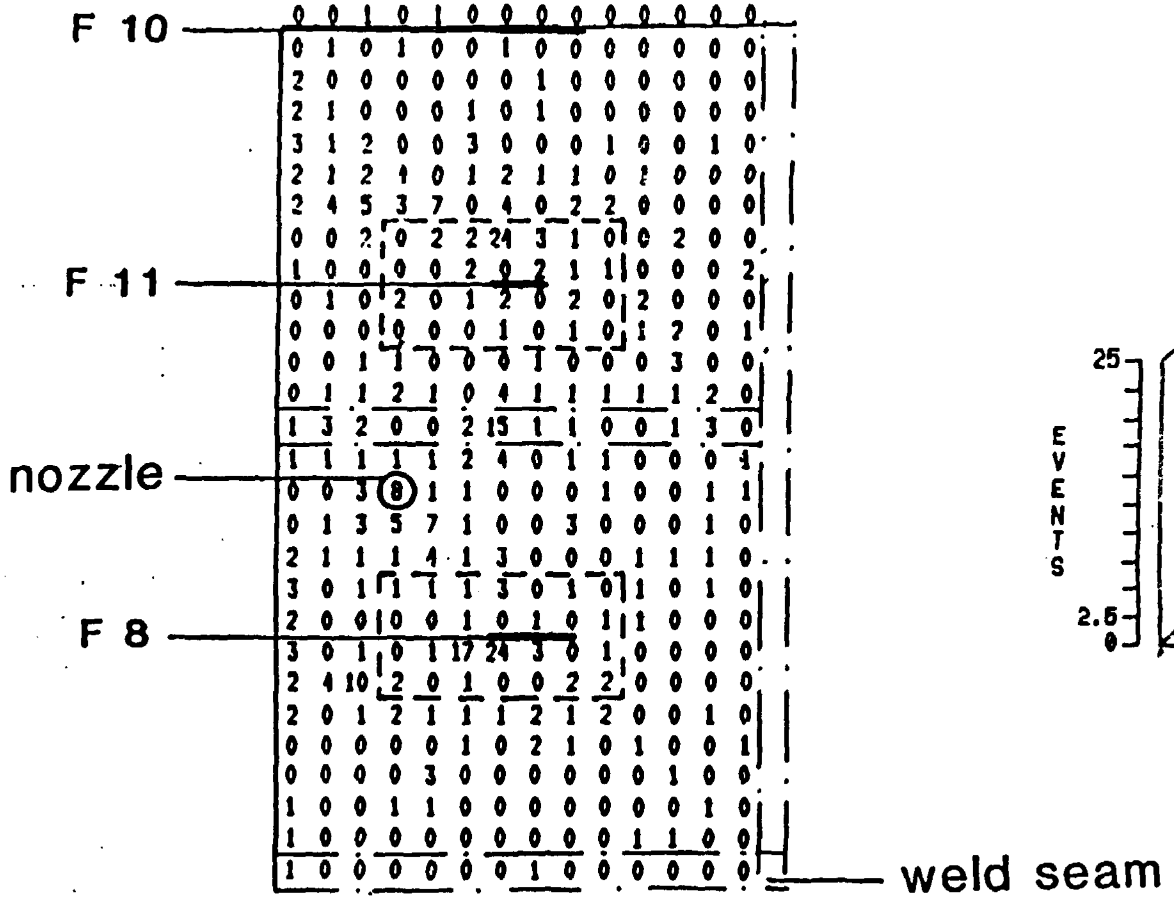
Transferfunktionen einer Biegeprobe
450x100x50 mm



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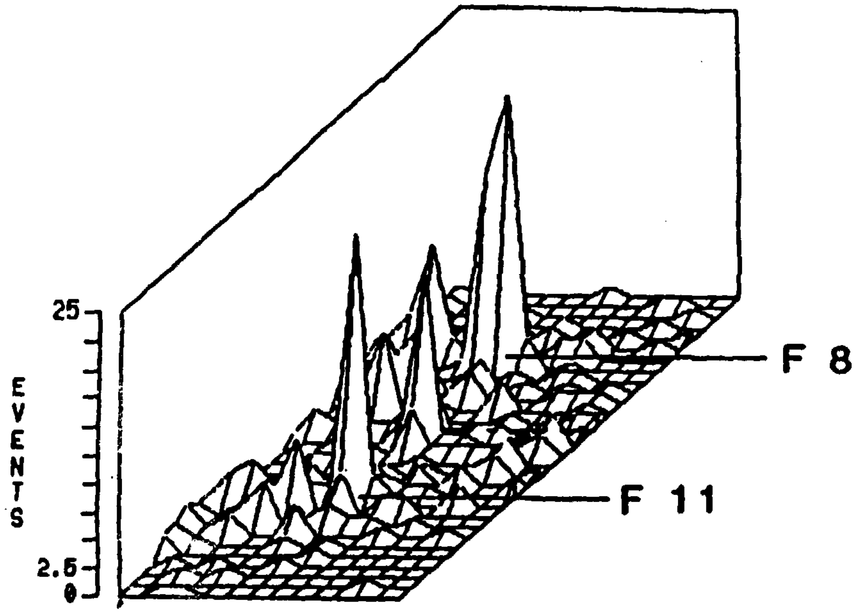

F:flaw

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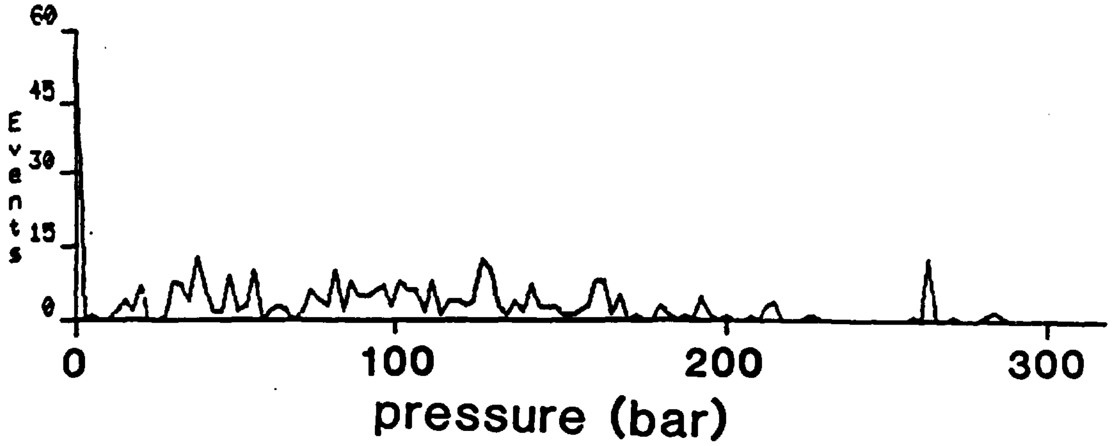
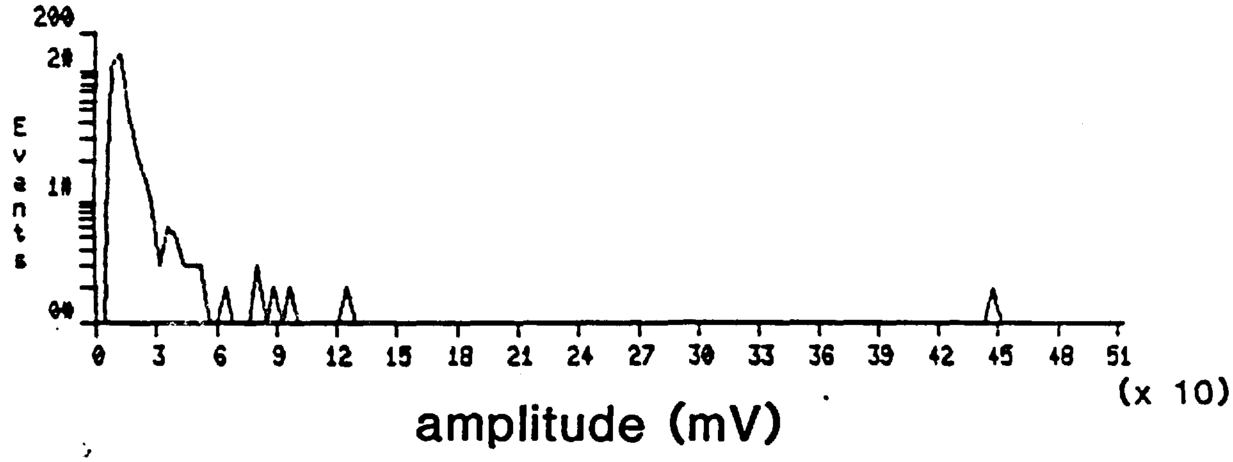
location result of the 1. hydrostatic test series



a) AE-distribution versus pressure



b) amplitude distribution

distributions of the AE-events of
the 1. hydrostatic test series

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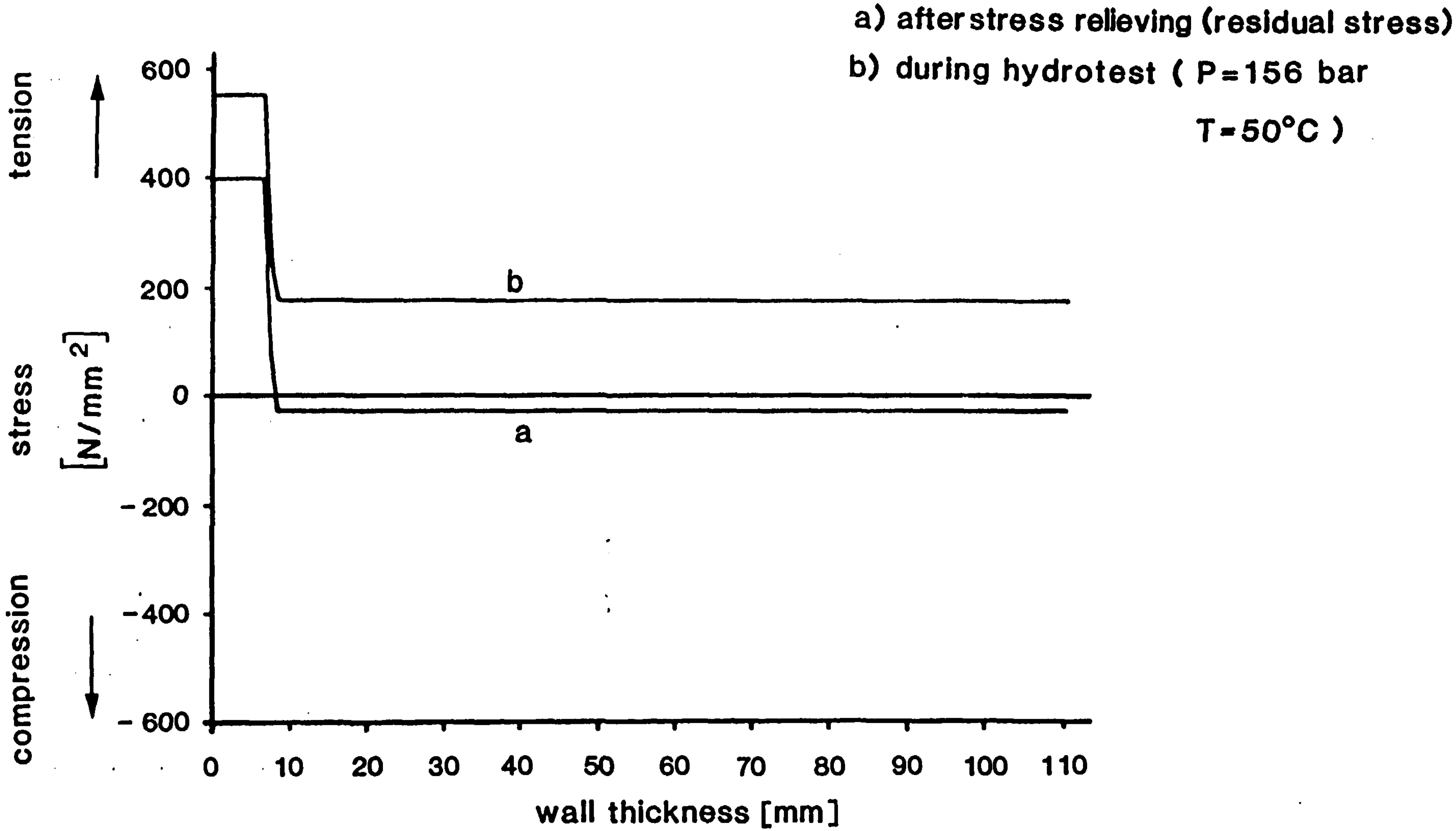

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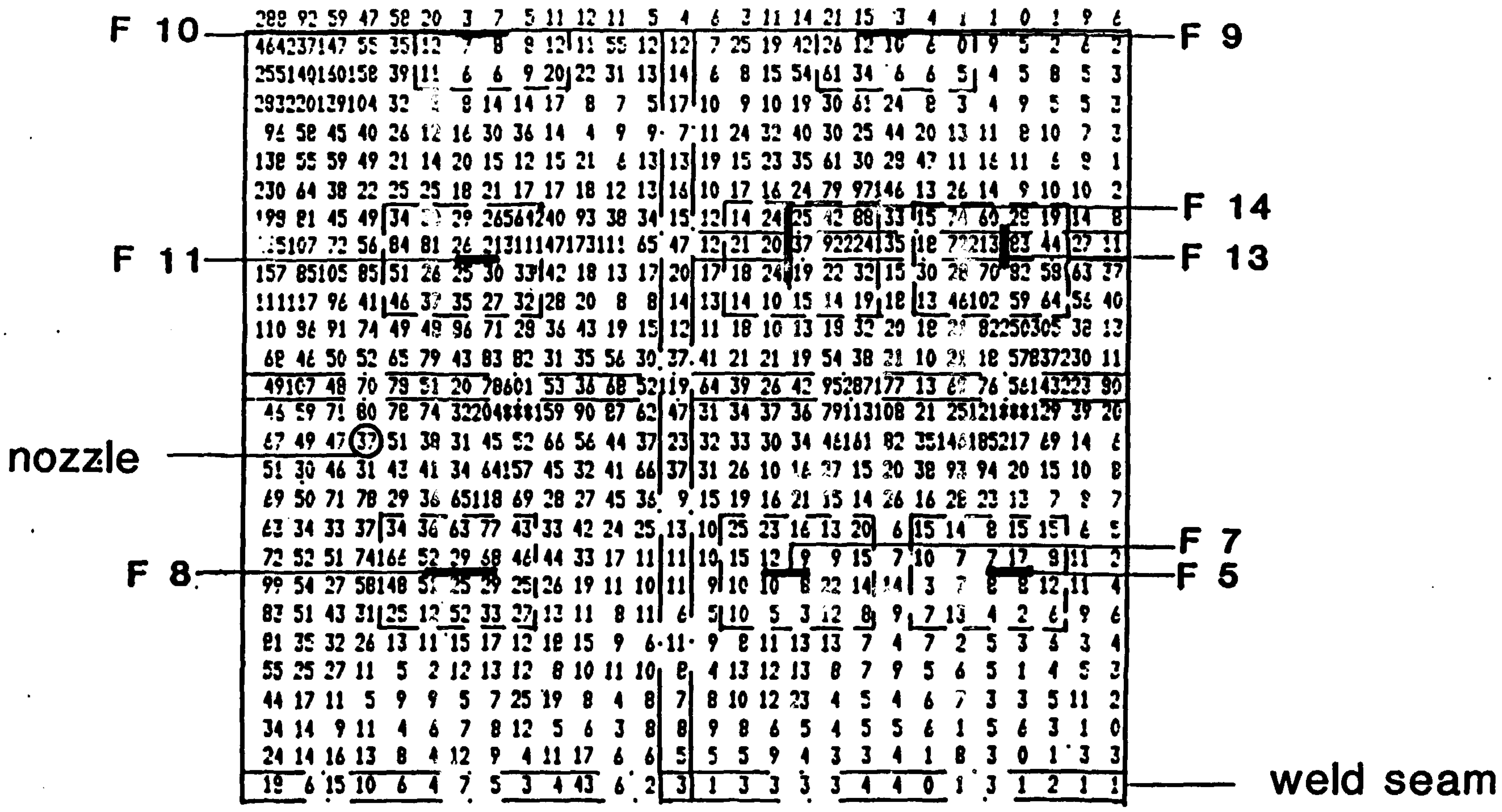
stress in the wall of a pressure vessel (HDR)

Figure 5



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F:flaw

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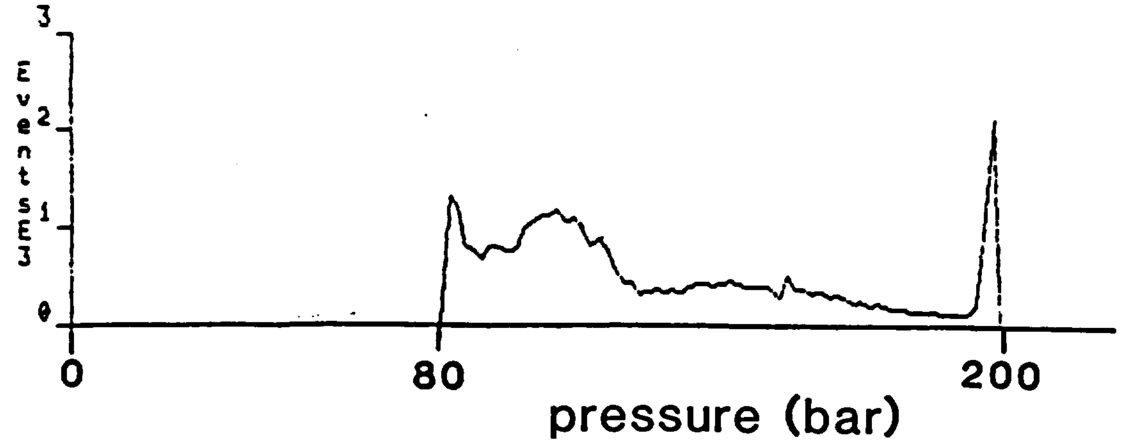
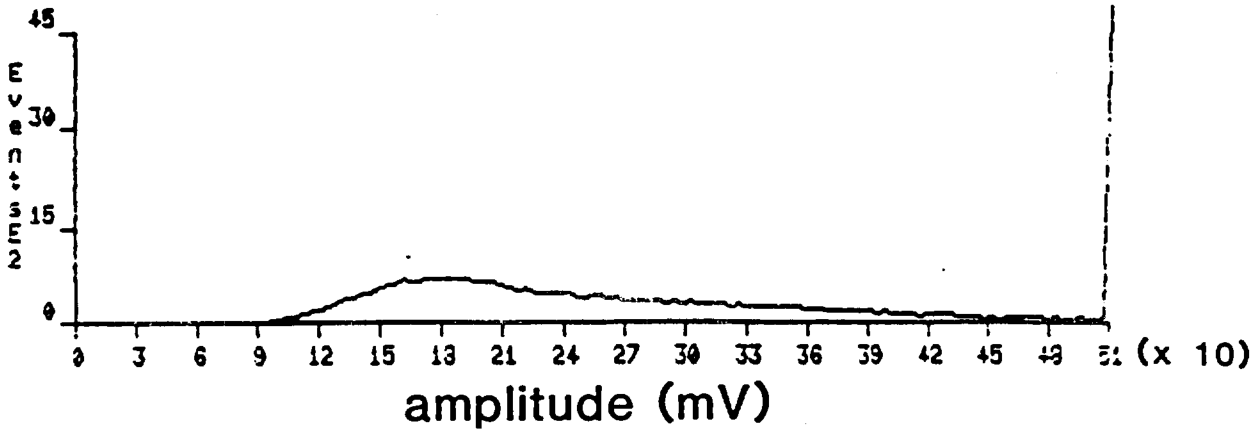
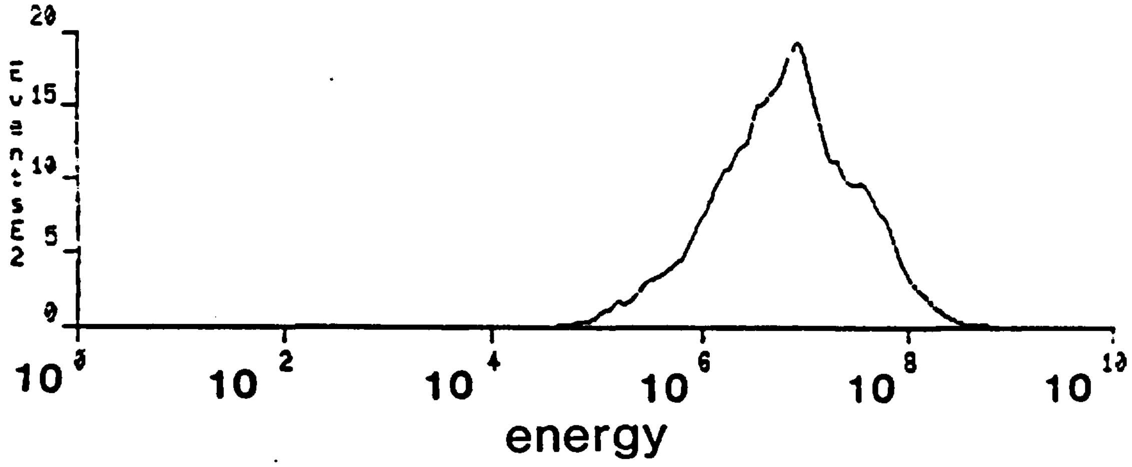
location result of 500 hot cycles



a) AE-distribution versus pressure



b) amplitude distribution



c) energy distribution

distributions of AE-events
of 500 hot cycles

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- runde Platten von 2 cm Durchmesser und 4 mm Dicke aus dichtem Alsint von Haldenwanger für Thermoschockversuche.

- Rohrabschnitte von ISD mit einer Länge von 29 mm, einem Durchmesser von 22 mm und einer Wandstärke von 3 mm für Thermoschockexperimente.

Die Biege- und Doppeltorsionsproben sind in Abb. 3 skizziert.

2.2. Versuchsaufbau

2.2.1 Prüfmaschine

Für die Doppeltorsionsversuche in Freiburg wurde die mechanische Prüfmaschine "IWON" eingesetzt, deren mechanischer Lastaufbringungsteil im IWM gebaut wurde und deren elektronischer Steuerteil von INSTRON stammt. Diese Maschine vermag auch sehr geringe Belastungsgeschwindigkeiten mit hoher Stabilität und Konstanz aufzubringen. Die Belastungsgeschwindigkeit betrug 500 s pro 1000 N beim schnellen Hochfahren der Last bzw. 30000 s pro 1000 N beim eigentlichen Versuch. Neben der Last wurde die Durchbiegung mittels Wegaufnehmer (induktiver LVDT) gemessen und von einem Computersystem auf Magnetkassette abgespeichert. Die Ermittlung der Rißgeschwindigkeit als Funktion der Spannungskonzentration erfolgte durch das Rechnersystem.

In der Universität Dortmund stand für die Dreipunktbiegeversuche eine mechanische INSTRON-Zerreißmaschine vom Typ 1193 (50 kN) zur Verfügung. Der Hottiger-Baldwin-Wegaufnehmer zur Messung der Probendurchbiegung war vom Typ W1T3. Die konstante Rate des Querhauptes lag bei 5 μm/min. Über eine an einem Mikroskop angeflanschte Videokamera konnte die Rißspitze sichtbar gemacht werden, wobei eine spezielle Beleuchtungsmethode zur Kontraststeigerung zwischen den beiden Probenhälften eingesetzt

- separation of crack growth and crack border friction by analysis of the signal parameters
- thermal shock:
  - detection of crack growth (fatigue, corrosion)
  - detection of crack border friction (compressive stress in the vessel wall)
- hydrotest:
  - no detection of non growing defects;
    no crack border friction (tensile stress in the vessel wall)

summary

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Nuclear Engineering and Design 106 (1988) 399–403
North-Holland, Amsterdam

RESULTS OF ACOUSTIC EMISSION DURING MECHANICAL AND THERMAL LOADINGS OF VESSEL COMPONENTS AND THEIR FRACTURE MECHANICAL INTERPRETATION

H. GRIES and E. WASCHKIES

Institut für zerstörungsfreie Prüfverfahren, Universität, Gebäude 37, 6600 Saarbrücken, Fed. Rep. Germany

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AE measurements are presented which were performed at pressure vessel components during different loadings: thermal shocking, hydrotest, cyclic loading. The tests were executed with the IzfP AE system. With this it is possible to locate the AE sources and to identify two source mechanisms: crack growth and crack flank friction.

The AE results are discussed and compared with the results of calculations about the residual stress in a cladded vessel wall:
- AE signals originating from crack growth processes are detected very sensitively.
- During thermal shock a lot of crack border friction occurs in consequence of compressive stresses on the crack flanks.
- However, during the hydrotests no crack border friction appears, because the crack flanks are mainly under tensile stresses.

1. Description of the AE system

According to the requirements of a modern measuring and analysis technique [1], IzfP has developed and built up an AE-system [2]. Briefly described the essential features of this system are:
- The AE signals are received by wide band transducers in 6 independent channels.
- The signal parameters are determined from the digitized signal by hardware components. The data rate amounts to about 1000 Sig./s.
- All received data are stored on a tape.
- It follows the location of the AE source and the signal parameters are transfer corrected to that source location.
- With the help of the source parameters a classification and an interpretation of the signals are done. So we can separate the signals emitted from crack growth and from border friction.
- The whole evaluation can be performed on-line or off-line.
- Lately the measurement of the absolute sensitivities of the AE sensors used in field can be done. Hitherto the transducers in field were calibrated only relatively. The absolute calibration bases on the reciprocity theorem and is executed entirely in an automatical way by a prototype device. The absolute sensitivity is concerning on Rayleigh waves or on longitudinal waves.

2. Applications

Till today this AE system was applied in different tests on pressure vessels:
- during thermal shock tests on components (i.e. wall, nozzle) of a reactor pressure vessel (HDR),
- during several thousands cyclic pressure loadings on large vessels (HDR, ZB2),
- during about 20 hydrotests on large vessels (HDR, ZB2, MPA-vessel).

3. Results of the AE measurements

3.1. Thermal shock

An example for the thermal shock is the test at a nozzle of a reactor vessel (A2-nozzle, HDR).

The experiment was carried out under operation conditions, that means at a temperature of 300°C and a hydrostatic pressure of 11 MPa. In one shock cycle the inner edge of the nozzle was cooled (with cold water, 20°C) and heated up (to 300°C) again. The cooling phase lasted 120 s and the heating phase about 240 s.

It was the aim to investigate the crack formation and the crack propagation under the conditions of thermal shock.

During the test a lot of AE signals could be received

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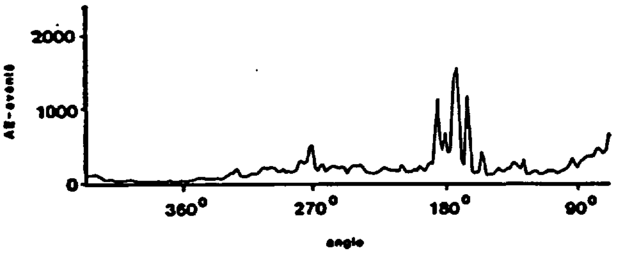


Fig. 1. AE-signals located around the nozzle during thermal shock.

and located around the nozzle (fig. 1). The analysis of the signal parameters shows that about 70% of the signals are of the type crack border friction and about 30% of the type crack propagation. In figs. 2a and 2b you see the distribution of crack propagation signals located in two different regions of the nozzle versus the time of one shock cycle. According to this, crack propagation occurs in the cooling phase as well as in the heating phase.

The crack growth in the cooling phase was expected and understood by fracture mechanics [3]. It is the fatigue crack growth according to the law of Paris. The concerning calculations show a good agreement with the AE-results (fig. 2a).

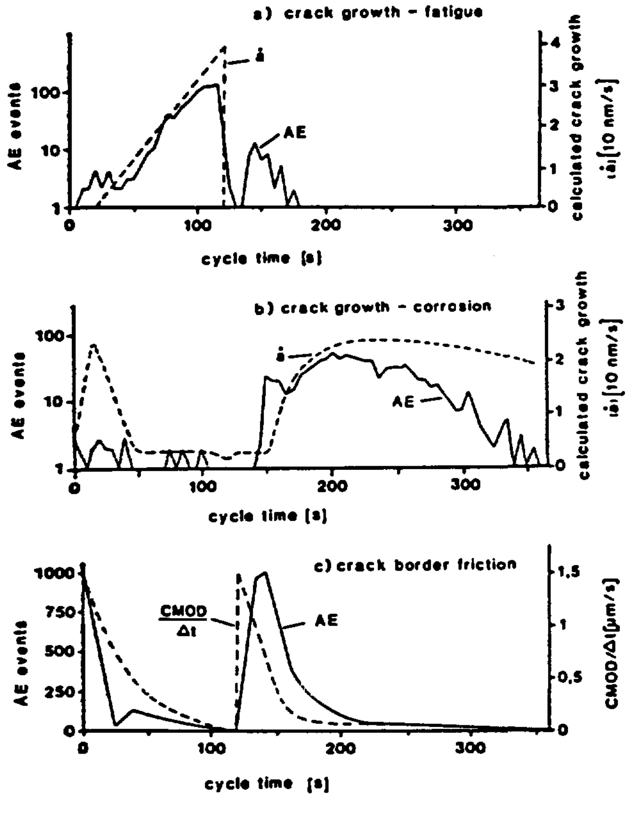


Fig. 2. Classification and interpretation of AE-signals.

On the contrary the crack growth in the heating phase was not understood at first. The fracture mechanics take in consideration a crack propagation by corrosion. Corresponding results from autoclave tests can be translated to the conditions of thermal shock [3]. A comparison between the so determined crack growth by corrosion and the results of the AE-measurements shows a good correlation (fig. 2b).

In fig. 2c the temporal appearance of the AE friction signals is plotted. These signals rise at the beginning of the heating phase, but also at the beginning of the cooling phase. CMOD-measurements at the defects verify that at these moments the greatest velocities of the crack borders exist [3].

3.2. Cyclic loading

The results during cyclic loadings are demonstrated by the example of the ZB2 vessel. In this vessel there were 14 crack-like defects. Several thousands cyclic loadings between a pressure of 8 and 15 MPa were imposed on the vessel (temperature of the filled in water: 240°C).

The aim of the experiment was to examine the crack propagation under operation conditions.

In fig. 3 you see the located AE-signals. The indications correspond to 4 defects. The analysis of the signal parameters leads to both signal types: crack border friction and crack propagation. Also ultrasonic tests show, that these defects have really propagated in depth.

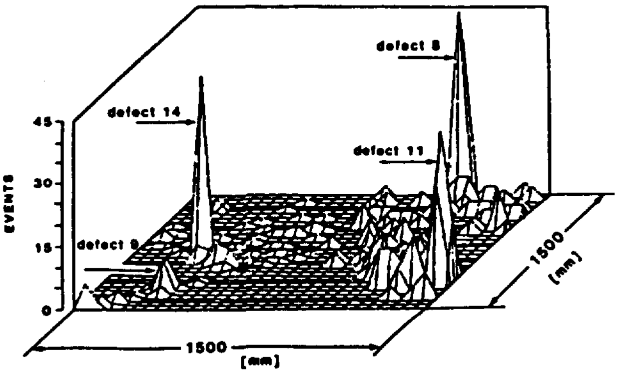


Fig. 3. Located AE-signals during cyclic loading (ZB2).

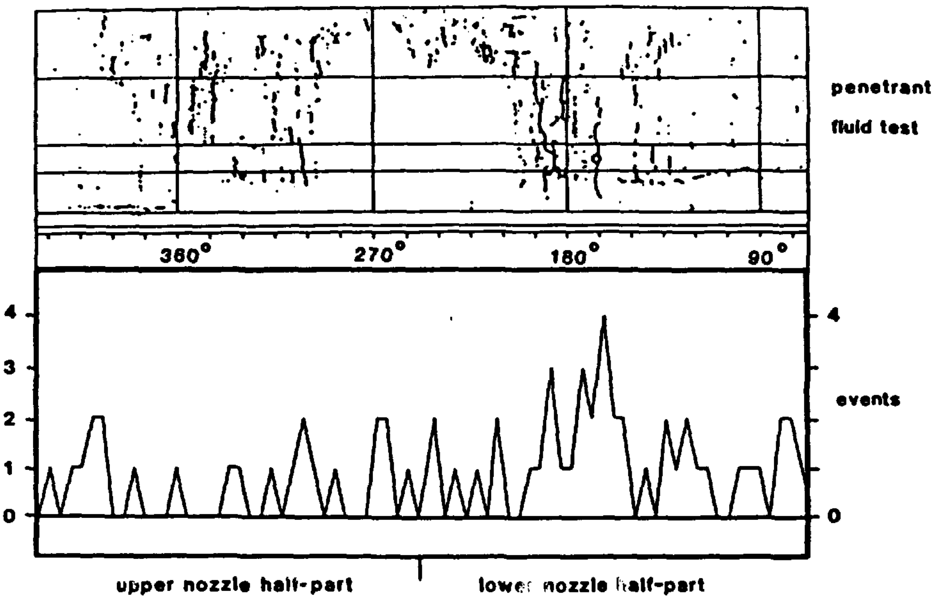


Fig. 4. Located AE-signals at the A2-nozzle during cold hydrotest of the reactor pressure vessel.

3.3. Hydrotest

In the last years a series of hydrotests were carried out on pressure vessels containing many defects. During these tests the load was small; so the defects should not grow further.

The question was: Can defects, which do not grow, be found by AE-test methods - especially by AE-signals from crack border friction.

The results is: No defect could be indicated by friction signals in a reliable way (MPA, ZB2). Only during the hydrotest on the nozzle (HDR) some few AE-signals were found (fig. 4) in spite of the high density of defects showed by the dye penetrant test. As expected all signals are of the type crack border friction.

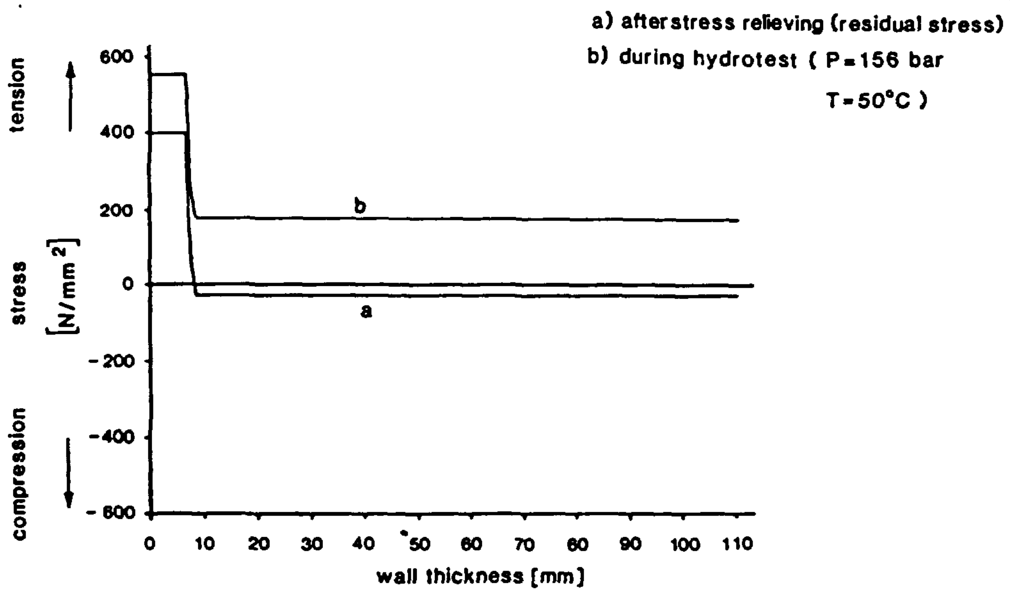


Fig. 5. Stress in the wall of a pressure vessel (HDR).

4. The state of stress in a vessel wall and the crack border friction

As mentioned above, the defects are not indicated by friction signals during hydrotests; whereas they are found very well by such signals during thermal shock.

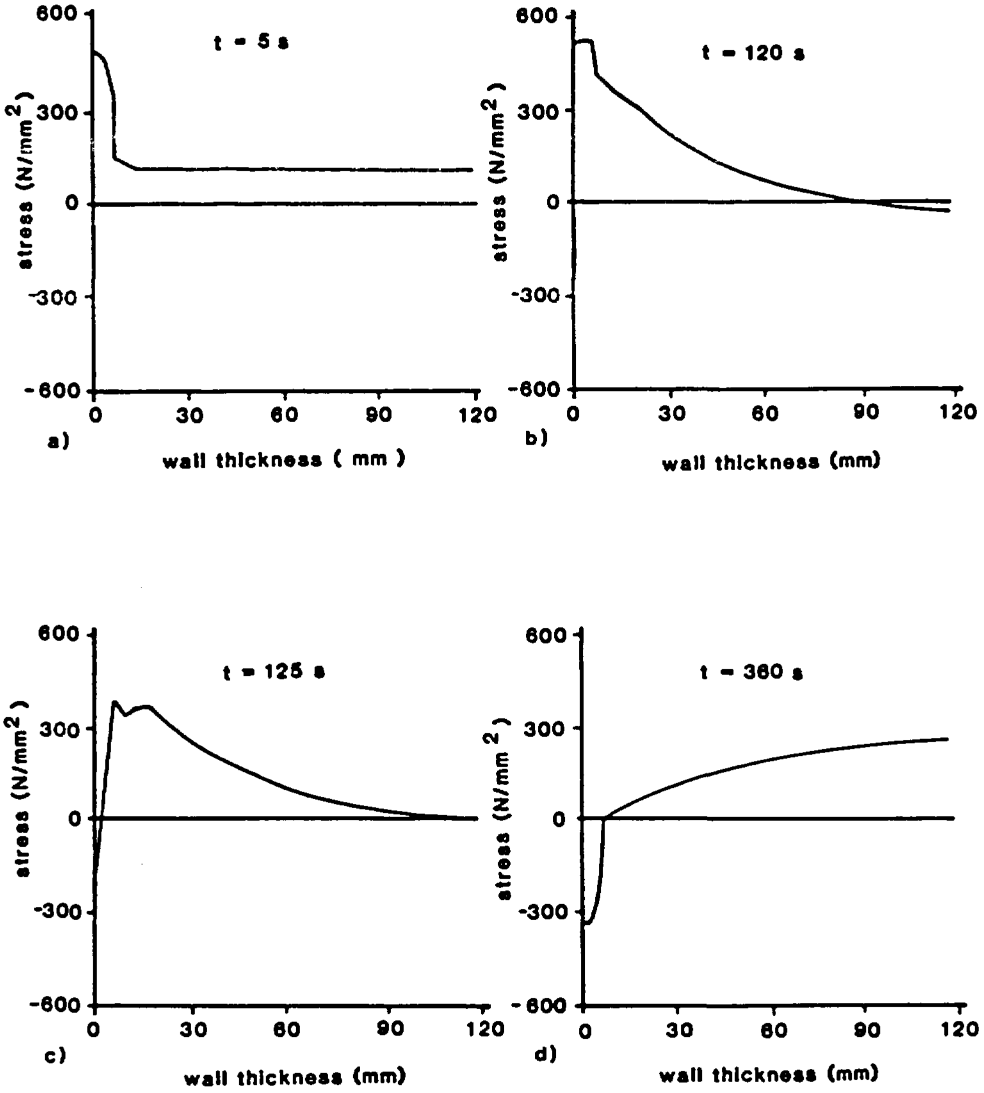
How can this situation be explained?

The suppositions for the existence of crack border friction are:

- There must exist a defect with touching flanks,
- on the crack flanks, there must be compressive stress components, and
- the crack borders must move relatively.

Recently the state of the residual stress in a cladded vessel wall was examined (fig. 5a); [4,5,6]: In the cladding there are high tensile stresses; on the other side in the base material there are small compressive stresses.

In the course of a hydrotest the total stress level is shifted into the region of tensile stress (fig. 5b). The suppositions for crack border friction are not given.



t: time after cooling

Fig. 6. Stress in the wall of a pressure vessel during thermal shock (HDR).

That is the reason why no or only few friction signals are found during the hydrotests. Also an increase of the level of the raising rate of the pressure doesn't produce more crack border friction.

Similar are the conditions during cyclic loadings: the stress oscillates between two levels. If the cyclic test is carried out between high pressure levels, there is no compressive stress and no crack border friction will be found. However it can be expected that during cyclic test with low pressures, friction will occur.

Totally different is the stress state in the vessel wall during the thermal shock. Fig. 6 shows the result of concerning calculations made by Mr. Neubrech: During and at the end of the cooling phase there exist high tensile stresses in the cladding. But at the start of the heating these tensile stresses are changing very rapidly in compressive stresses. Then again at the beginning of the cooling phase the compression passes to tension. So the conditions for crack border friction – compressive stress and motion – are given at the beginning of the heating phase and again at the beginning of the cooling phase. This agrees very well to the results of AE which has measured the highest activity of friction signals at these moments (fig. 2c).

5. Summary

- During vessel trials AE-signals from crack border friction and from crack propagation can be separated by the analysis of the signal parameters.
- AE-results during thermal shock: Crack growth is detected very sensitively (detection limit: 1–5 mm^2 crack area). Also crack border friction is detected in consequence of compressive stresses on the crack flanks.
- AE-results during hydrotest: Defects which do not grow during the experiment are not indicated. No crack border friction appears, because the crack flanks are mainly under tensile stresses.

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